

Issues and Challenges in Situation Assessment (Level 2 Fusion)

ERIK BLASCH
IVAN KADAR
JOHN SALERNO
MIECZYSLAW M. KOKAR
SUBRATA DAS
GERALD M. POWELL
DANIEL D. CORKILL
ENRIQUE H. RUPINI

Situation assessment (SA) involves deriving relations among entities, e.g., the aggregation of object states (i.e., classification and location). While SA has been recognized in the information fusion and human factors literature, there still exist open questions regarding knowledge representation and reasoning methods to afford SA. For instance, while lots of data is collected over a region of interest, how does this information get presented to an attention constrained user? The information overload can deteriorate cognitive reasoning so a pragmatic solution to knowledge representation is needed for effective and efficient situation understanding. In this paper, we present issues associated with Level 2 Information Fusion (Situation Assessment) including: (1) user perception and perceptual reasoning representation, (2) knowledge discovery process models, (3) procedural versus logical reasoning about relationships, (4) user-fusion interaction through performance metrics, and (5) syntactic and semantic representations. While a definitive conclusion is not the aim of the paper, many critical issues are proposed in order to characterize future successful strategies for knowledge representation, presentation, and reasoning for situation assessment.

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Authors' addresses: E. Blasch, AFRL, Dayton, OH; I. Kadar, Interlink Systems Sciences, Inc.; J. Salerno, AFRL, Rome, NY; M. M. Kokar, Northeastern University, Boston, MA; S. Das, Charles River Analytics, Cambridge, MA; G. M. Powell, U.S. Army RDECOM CERDEC I2WD, Ft. Monmouth, NJ; D. D. Corkill, Univ. of Massachusetts, Amherst, MA; E. H. Ruspini, Artificial Intelligence Center, SRI International, Menlo Park, CA.

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1. INTRODUCTION

Situation assessment (SA) is an important part of the information fusion (IF) process because it (1) is the purpose for the use of IF to synthesize the multitude of information, (2) provides an interface between the user and the automation, and (3) focuses data collection and management. Hall and Llinas (Table I) have listed a variety of techniques that need to be solved for SA to be viably implemented in real systems [15]. Since the late 1990s there has been few cumulative updates in the progress of SA and still there are remaining issues and challenges. During the FUSION05 conference, Ivan Kadar organized, moderated, and participated in a panel discussion with invited leading experts to elicit and summarize current issues and challenges in SA that need to be researched in the next decade.

1.1. Panel Participants, Topics, and Perspectives

This paper serves as a retrospective view of the panel discussion that was held in July 2005. In this format, we list our retrospective and annotated view of the panel information in a condensed (bulletized) format to make it easier for the reader to assimilate the general concepts. Due to space limitation, only a few key issues are expanded on in text format.

- Organizer: Ivan Kadar, Interlink Systems Sciences, Inc.
- Co-Organizers: Subrata Das, Charles River Analytics and Mieczyslaw M. Kokar, Northeastern University
- Moderators: Ivan Kadar, Interlink Systems Sciences, Inc. and James Llinas, SUNY at Buffalo
- July 26, 2005 FUSION 2005—The 8th International Conference on Information Fusion, July 25–28, Philadelphia, PA

PARTICIPANTS AND PRESENTATION TITLES

- “Knowledge Representation Issues in Perceptual Reasoning Managed Situation Assessment” Ivan Kadar, Interlink Systems Sciences, Inc., Lake Success, NY
- “Knowledge Representation Requirements for Situation Awareness” John Salerno, Douglas Boulware, Raymond Cardillo, Air Force Research Laboratory, Rome Research Site, NY
- “Situation Assessment: Procedural versus Logical” Mieczyslaw M. Kokar, Department of Elect. & Computer Eng., Northeastern University, Boston, MA
- “Tactical Situation Assessment Challenges and Implications for Computational Support” Gerald M. Powell, U.S. Army RDECOM CERDEC I2WD, Ft. Monmouth, NJ
- “Situation Assessment in Urban Combat Environments” Subrata Das, Charles River Analytics, Inc., Cambridge, MA

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TABLE I
SA Challenges and Limitations—Hall and Llinas, [15]

JDL Process	Processing Description	Current Status	Challenges and Limitations
Level 2	Develops a description of current relationships among objects and events in the context of the environment (i.e., situation assessment)	Numerous prototypes Dominance by Knowledge-Based Systems (KBS) —Blackboard methods —Rule-based representation —Logical templates KBS experiments —Case based reasoning, Fuzzy Logic Non-real time implementation	Dominated by prototypes No experience on scaling to field models “Excedrin” cognitive models Difficult KB development Perfunctory Test & Evaluation Integration of identity/kinematic data

- “Representation and Contribution-Integration Challenges in Collaborative Situation Assessment” Daniel D. Corkill, University of Massachusetts, Amherst, MA
- “Human-Aided Multi-Sensor Fusion” Enrique H. Ruspini, et al., Artificial Intelligence Center, SRI International, Menlo Mark, CA
- “DFIG Level 5 (User Refinement) issues supporting Level 2 (Situation Assessment)” Erik Blasch, AFRL, WPAFB, OH

1.2. Common Themes

While discussion of individual research results by the participants highlighted specific key issues, there were common themes that resulted from the panel discussion. The common themes were:

COMMON ISSUES

- User—The SA process includes perceptual, interactive, and human control
- Process models—updating behavioral models (e.g. Bayes Nets, procedural/logical, perceptual, learning)
- Context—operational situation (i.e., dependent on the current state of the environment)
- Meaning—semantics and syntax issues (formal methods, ontologies)
- Metrics—develop a standard set of metrics (e.g. trust, bounds, uncertainty)

COMMON CHALLENGES

- Explanation of process—evidence accumulation and contradiction in knowledge representation and reasoning
- Graphical displays to facilitate inferential chains, collaborative interaction, and knowledge presentation
- Interactive control for corrections and utility assessment for knowledge management

2. SITUATION AWARENESS/SITUATION ASSESSMENT

There are two main communities that are looking at situational information (i.e., Situation Awareness

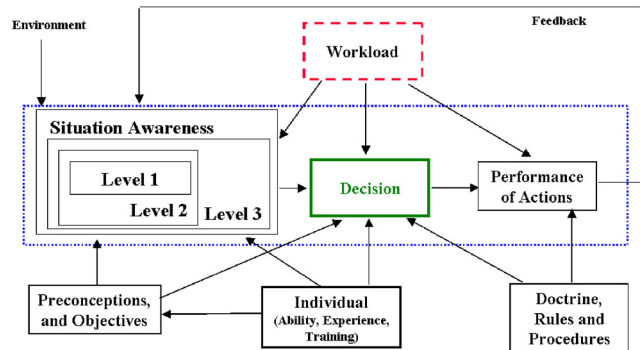


Fig. 1. Endsley's situation awareness model.

(SAW) and Situation Assessment (SA)): the human factors community and the engineering information fusion (IF) research community. SAW is a mental state while SA supports (e.g. fusion products) that state. The human factors notion of SAW is being lead by Mica Endsley [12]. For the IF society, there are many leading people proposing different aspects of SAW research. Research is a way to categorize developments, but another way is by applications. There are many application communities looking at SAW research including: military, medical, aviation, security, and environmental. Each might have differences, but the commonality rests in the fact that a multitude of data needs to be synthesized into a single operating picture (dimensionality reduction) [37]. Likewise, the salient information needs to be provided to the user to assist the user in completing their mission tasks.

2.1. Situational Awareness Models

The Human in the Loop (HIL) of a semi-automated system must be given adequate situation awareness. According to Endsley “SAW is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.” [12]. This now-classic model, shown in Fig. 1, translates into 3 levels:

- Level 1 SAW—Perception of elements in the environment



Fig. 2. Fusion situation awareness model [4].

- Level 2 SAW—Comprehension of the current situation
- Level 3 SAW—Projection of future states

Operators of dynamic systems use their SAW in determining their actions. To optimize decision making, the SAW provided by an IF system should be as precise as possible as to the objects in the environment (Level 1 SAW). A SA approach should present a fused representation of the data (Level 2 SAW) and provide support for the operator's projection needs (Level 3 SAW) in order to facilitate the operator's goals. From the SA model presented in Fig. 1, workload is a key component of the model that affects not only SAW, but also the decision and reaction time of the user.

2.2. User Fusion Model

As another example, the Situational Model components [32], shown in Fig. 2, developed by Roy, show the various information needs to provide the user with an appropriate SAW. To develop the SA model further, we note that the user must be primed for situations to be able to operate faster, and more effectively.

A fusion system must satisfy the user's functional needs and extend their sensory capabilities. Of interest to the information fusion community are IF systems which translate data about a region of interest into knowledge, or at least information over which the human can reason and make decisions. A user fuses data and information over time and space and acts through their world mental model—whether it be in the head or with graphical displays, tools, and techniques. The current paradigm for fusion research, shown in Fig. 3, is called the user-fusion model [5].

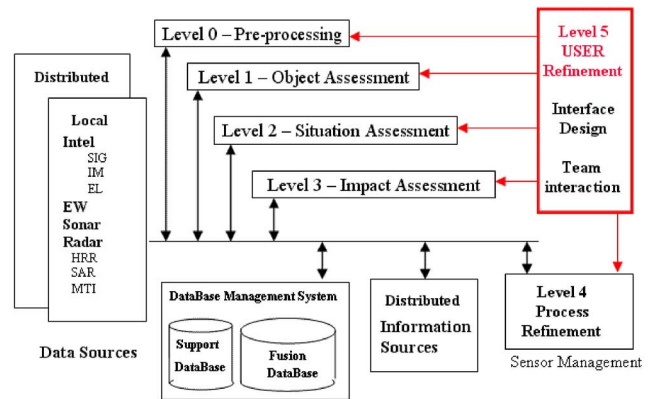


Fig. 3. User fusion model.

2.3. Perceptual Reasoning Managed Situation Assessment

“Knowledge Representation Issues in Perceptual Reasoning Managed Situation Assessment” Ivan Kadar

The IF community has had several definitions of SA over time. The JDL Model [14], defined SA as “estimation and prediction of relations among entities, to include force structure and cross force relations, communications and perceptual influences, physical context, etc.” DSTO [11, 22] defined SA as “an iterative process of fusing the spatial and temporal relationships between entities to group them together and form an abstracted interpretation of the patterns in the order of battle data.” Issues with the SA definitions, and some subsequent models based on these definitions are:

- not domain independent,
- do not incorporate human thought processes, human perceptual reasoning, the ability to control sensing and essence of response time,

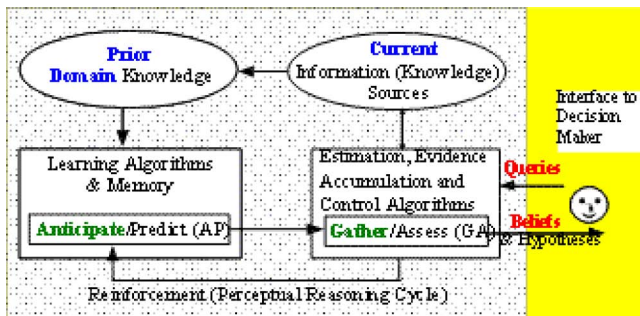


Fig. 4. Perceptual reasoning machine.

- imply use of limited a priori information,
- and only imply potential for new knowledge capture.

Therefore, the desired properties of SA are:

- One needs the ability to control Levels 1–4 of Data Fusion processes for knowledge capture in SA
- SA is to establish relationships (not necessarily hierarchical) and associations among entities, it should anticipate with a priori knowledge in order to rapidly gather, assess, interpret and predict what these relationships might be; it should plan, predict, anticipate again with updated knowledge, adaptively learn, and control the fusion processes for optimum knowledge capture and decision making
- These features are similar to the characteristics of human perceptual reasoning
- Therefore it is conjectured that the “optimum” SA system should emulate human thinking as much as possible

As a matter of fact, the godfather of the Internet and knowledge representation, Vannevar Bush [8] in his famous 1945 essay, “As We May Think” stated, op. cit., “The human mind does not work that way hierarchically. It operates by association.” Spatial and temporal associations are key ingredients of Perceptual Reasoning Model (PRM).

The goal is the perceptual reasoning model which is viewed as a “meta-level information management system,” as shown in Fig. 4. PRM consists of a feedback planning/resource control system whose interacting elements are: “assess,” “anticipate” and “predict” [16–18].

- Gather/Assess current, Anticipate future (hypotheses), and Predict information requirements and monitor intent,
- Plan the allocation of information/sensor/system resources and acquisition of data through the control of a separate distributed multisource sensors/systems resource manager (SRM),
- Interpret and act on acquired (sensor, spatial and contextual) data in light of the overall situation by interpreting conflicting/misleading information.

Representative elements and knowledge bases, associated with the assess, anticipate and predict PRM modules, are categorizable into: (1) functions, with each function further categorized into (a) knowledge required, (b) knowledge acquisition methods, (c) knowledge representation approaches, and (d) implementation techniques. Specific knowledge representation and reasoning (KRR) methods were discussed at the panel highlighting implementation issues and research challenges.

Issues for SA

1. Knowledge—a priori and current
2. PROCESS—anticipate and gather facts
3. User queries instantiation
4. Fusion System presents Beliefs
5. Need a process model interface

KRR Challenges for SA

1. Adequacy of KRR (logic, ontology, algorithmic, probabilistic), how to quantify/measure?
2. Expressiveness of models versus tractability of inference
3. Managing Complexity (how to bound problem w/incomplete knowledge)
4. Data Information (How to manage heterogeneous and uncertain KSs and detect duplicate or incomplete concepts)
5. Presentation of knowledge to different users (what is pragmatic?)

2.4. Syntactic Algorithms and Semantic Synonyms

“Knowledge Representation Requirements for Situation Awareness” John Salerno, Doug Boulware, Ray Cardillo

Full Spectrum Dominance (FSD), as defined by Joint Vision 2020, is the ability to be persuasive in peace, decisive in war and preeminent in any form of conflict. FSD cannot be accomplished without the capability to know what the adversary is currently doing as well as the capacity to correctly anticipate the adversary’s future actions. This ability of projection is an element of Situation Awareness [12, 13]. SA has received increased attention due to its diverse applications in a number of problem domains including: asymmetric threat, tactical, cyber, and homeland security [14]. Salerno, et al. proposes an architecture that combines the Endsley and JDL models (shown in Fig. 5) and has applied this model to various strategic, cyber and tactical applications [35].

Through a display, a user can (1) build a model by either editing an existing template/model or create a new one; (2) activate/de-activate existing models; or (3) view active models and any evidence that has been associated with the model over time. Different political, military, economic, social, infrastructure, and information models can be accessed and the result published (or subscribed) to.

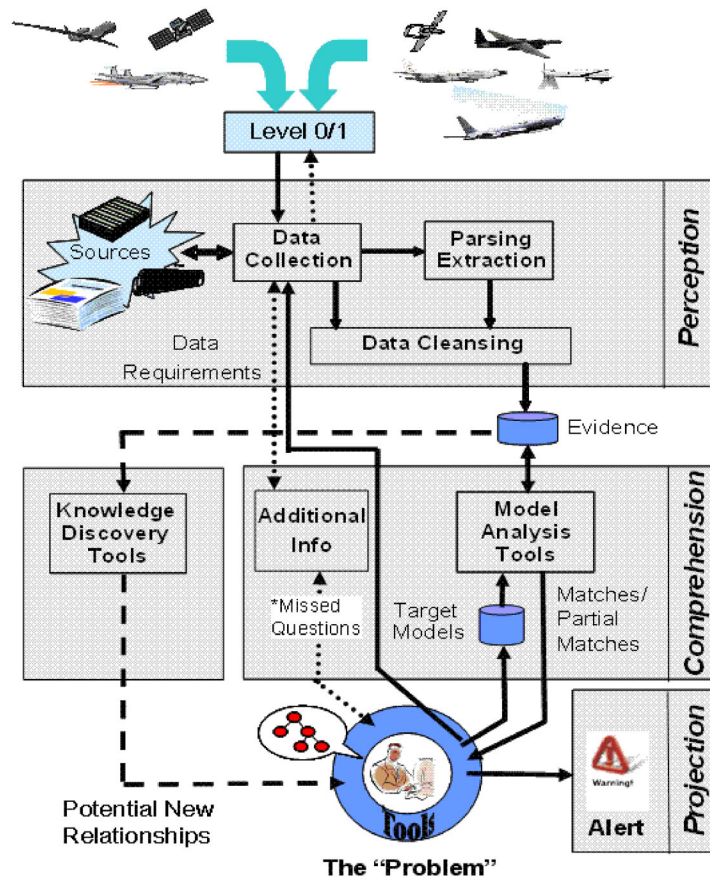


Fig. 5. SA framework.

Issues encountered in its development mainly pertain to evidence access, storage, usage and providing a priori knowledge. In order to resolve any semantic issues in context and value, we need to normalize the data before we can use it. Data normalization involves converting different formats of the same data into a common representation. Dealing with semantic inconsistencies is much more difficult. In these cases, we need to resolve synonyms both in what is represented and what the value itself represents. Two different labels can have the same meaning, or two aliases can represent the same entity. Finally, what level of a priori data is needed depends on the context of operation.

Issues for SA

1. Lots of data for analyst, but not able to get it
2. Analyst—under stress and fatigue
3. What to publish and subscribe
4. Security issues in data gathering

Challenges for SA

1. Syntactic algorithms (normalization/transformation)
2. Semantic synonyms (different meaning between ideas)
3. Learning from what is presented
4. People can think of new situations

2.5. Procedural versus Logical

“Situation Assessment: Procedural versus Logical” Mieczyslaw M. Kokar

Various terms have been used to refer to Level 2 fusion processing: situation refinement, situation awareness, situation development, relation estimation and other. All of these terms have a common part in their definition, i.e., all of them require that the definition should include the knowledge of all the relevant objects and their kinematic states. This is essentially a Level 1 function, so it will not be discussed here. Some of the definitions, but not all, include the requirement of knowing relationships among the objects. This brings three problems: 1) The relevance problem: there are so many possible relations—which ones are relevant? 2) The resource problem: where can we get the necessary information resources, both data and processing, that can be used to assess the current situation? 3) The derivation problem: how do we derive whether a particular relation holds or not? And even fewer definitions capture the aspect of awareness as defined in the Webster dictionary, where awareness is explained as “AWARE implies vigilance in observing or alertness in drawing inferences from what one experiences.” In other words, a subject is aware if the subject not only observes (experiences) the objects but also is capable of drawing conclusions from

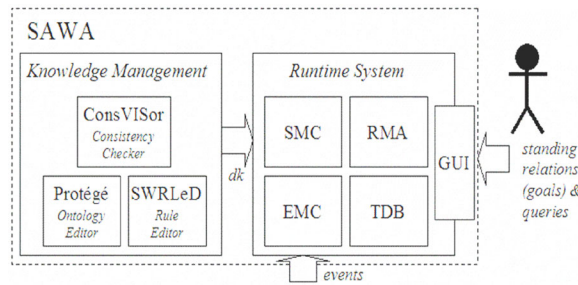


Fig. 6. SAWA. Situation management component (SMC), relation monitor agent (RMA), triples data base (TDB), and event management concept (EMC).

these observations. We call this the inference problem: how can we infer the implications of a specific situation on the tasks that we are pursuing?

The observations presented in this paper have been collected during the two year period of working on the situation awareness assistant (SAWA), shown in Fig. 6 [27]. In most general terms, SAWA is an ontology based situation monitor [26]. Its main goal is to monitor a “standing relation,” i.e., a query formulated in terms of an underlying ontology. SAWA collects information (events) and invokes its inference engine that derives whether the relation holds or not. The reasoning mechanism of SAWA combines logical inference with Bayesian belief propagation. A number of findings from this project have been published in papers [20, 21, 26, 27, 28].

Solutions are sought by either procedural or logical (declarative) means. In the logical approach, a query about a specific relation can be posed to an inference engine (or a theorem prover). The inference engine then returns an answer, possibly with some variable bindings. A number of inference engines for OWL have been developed and/or are under development. In typical data fusion applications the derivation problem is solved in a procedural way, i.e., in order to determine whether a particular relation holds or not, a procedure is invoked, which returns either a “yes” or a “no” answer, possibly also including some return parameters. While this approach may turn out to be more efficient in terms of time complexity, it lacks the genericity that the logical approach has. The limitation comes from the fact that only those queries for which procedures have been explicitly coded by the system developer can be answered. The logical approach is termed declarative programming, while the procedural approach is called procedural programming.

In the logical approach, the inference problem is closely related to the relation derivation problem. A logical query regarding any feature of a situation is posed to an inference engine. The query language for OWL is called OWL-QL. The number of types of queries is only limited by the complexity of the ontology that captures the domain knowledge. The queries are built out of the class expressions and property expressions using logi-

cal connectives that are part of the ontology language. Again, the advantage of the logical approach is that the query engine is not designed to answer a specific set of queries, but it is rather generic, capable of answering any query that is expressible in the query language. This is not the case in the procedural approach, where only those queries that have been formulated at the design time can be resolved by the system. The reasoning mechanism of SAWA combines logical inference with Bayesian belief propagation. Although the logical approach is a promising approach to solve the general SA problem, still, a number of issues need to be resolved in order to make the logical approach scalable up to the real world problems.

Issues for SA

Relations—Future in Semantic Web approach

1. Relevance—need a generic relevance theory
2. Resource—from closed (level 1 provides all information) to open (level 2 accesses Semantic Web for additional knowledge)
3. Derivation/Inference—expressiveness versus efficiency of reasoning

Challenges for SA

1. Consistency and ontology mapping
2. Identity crisis (association problem)
3. Representational expressiveness, computational complexity
4. Trust Metrics
5. “Semantic Web”—use standard language (i.e. “OWL”), but need more expressiveness (rules)

3. USERS AND APPLICATIONS

3.1. Tactical SA and Computational Support

“Tactical Situation Assessment Challenges and Implications for Computational Support” Gerald M. Powell

A number of definitions of Level 2 fusion are available [2, 3, 23]. The comments in this paper relate to one or more of these definitions. The operational focus is Army brigade intelligence analysis. There exist approaches to instantiate these definitions into practical designs [3]. Fig. 7 shows the representational information from Waltz [36] which shows the context-dependent perceptual knowledge views for processing. These displays show spatial and temporal relations from which to act. The display technology is domain dependent and requires operational considerations [30–31]. What follows is a small subset of key issues and challenges in knowledge representation and reasoning methods for Level 2 fusion in this task domain.

Hypotheses and Their Utilities: There is a need to generate hypotheses to serve as predictors of behavior, to guide information gathering, and to provide a framework for constructing plausible explanations for evidence. The goal of creating hypothesis structures that

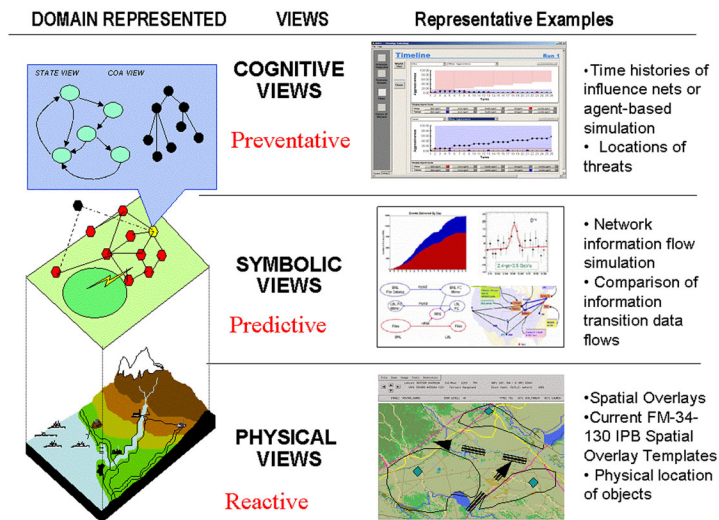


Fig. 7. Categories of view.

will satisfy these purposes would indicate an adequate understanding exists of the hypothesis types required and the logical relationships among them. The relative importance of a given hypothesis in the structure will be context-dependent—this requires analysis. Similarly, the relative value of reports/data from differing source types and instances will be context-dependent. Like hypotheses, their relevance or value, will vary over time as the situation unfolds including what information has already arrived, whether it has been analyzed, the quality of it, its relative importance and so on. A report deemed irrelevant in a particular context may, much later, become relevant as the interpretation has evolved. Analysis and interpretation are context-dependent. They must take place within the set of context-dependencies defined by the information peculiar to a given situation (mission, terrain, battlespace reports, etc.) as well as historical knowledge about the adversary. These dependencies can cause combinatoric growth in the number of interpretations possible and lead to erroneous analyses and conclusions. Identifying what these dependencies are, and constructing ways to represent and reason with them to produce increased accuracy and speed of analysis and interpretation remain open issues.

Weak Models of the Adversary: In some situations, our knowledge of the actors we are observing and trying to understand may be extremely weak such as when there has been little opportunity for information gathering prior to engagement, when their organizational elements and communications patterns are partitioned in ways that inhibits discovery of structure, and when their doctrine and tactics encourage rapid, adaptive changes in behavior sometimes manifesting in unexpected ways. Even when opportunities for observation are plentiful, accurately interpreting data in a timely manner may be extremely difficult due to indicators that are weak discriminators of hypotheses. These issues indicate there are implications for both directed and undi-

rected machine-based knowledge discovery. Also, models and tools to help analysts understand situational-specific risks of Type I (false positive) and II (false-negative) errors in interpretation would be useful.

Multiple Inferencing Strategies: Abductive, deductive and inductive inferencing are present in human performance in situation assessment. There are implications for machine capabilities to support each of these in an integrated framework. Their machine implementations should be such that they support user understanding, trust and acceptance.

Issues for SA

1. Massive information overload on analysts
2. Analysis and interpretation are context-dependent
3. Cognitive biases cause errors in analysis and interpretation
4. Models of adversary structure/behavior are often weak
5. Heterogeneous, non-integrated information sources
6. Automated environments supporting adequately fast, direct authoring of knowledge by analysts do not exist

Challenges for SA

1. Automated analysis/interpretation that is fast enough while also being accurate
2. Overcoming representational and processing complexities caused by context-dependence
3. System designs that will help analysts overcome cognitive biases
4. Automatic adaptation to changing threats
5. Semantic consistency across info sources
6. Building adequate knowledge authoring environments for analysts

3.2. Urban Combat

“Situation Assessment in Urban Combat Environments” Subrata Das

The two largest hurdles for SA in contemporary urban combat environments are the environmental clutter

ter and the enemy's lack of conformity to established tactical doctrine. Adversarial entities in the environment must be identified and tracked, individually or as groups, to recognize higher-level situations (e.g. attack, ambush, interdiction, insurgency) and determine effective military responses or preemptive actions. Furthermore, because contemporary enemy behavior is often innovative and unpredictable, traditional tactical models cannot be applied to recognize significant developments in contemporary situations. As a result, an effective automated means for extracting useful situation information from the thousands of multi-source events generated every minute in the theatre of operations remains an open problem. Human analysts currently perform the bulk of this difficult situation and threat assessment work, but are only able to process a small fraction of the available data. Knowledge discovery (aka. data mining) is a process of abstracting knowledge from data to form models for problem solving. Knowledge discovery techniques such as Decision Trees and Inductive Logic Programming discover association rules between items within an unordered collection of records, transactions, or events. Techniques also exist for extracting causal Bayesian belief network (BN) structures along with their strengths. BN technology offers several advantages, including its easy-to-understand graphical modeling and consistent probabilistic semantics in dealing with the uncertainty involved in sensor data. Focusing now on the model-based approach, current state-of-the-art approaches for answering the commander's priority intelligence requirements (PIRs) for SA are model-based. Knowledge discovery or model-based approaches fail to provide a complete solution for SA requirements because a) they can only model specific patterns within a relatively small subset of voluminous data, and b) there is never enough historical data available to model novel phenomena. To address these issues, we explore a hybrid approach combining model-based reasoning with knowledge discovery techniques for SA, especially suitable for detecting and identifying asymmetric threats in urban environments. The proposed hybrid approach leverages the wealth of data available to provide information about "what is strange" about a given situation, without having to know what exactly what it is we are looking for, thus triggering models for follow-up SA.

The hybrid approach recognizes significant patterns by taking into account environmental clutter. It also uses spatiotemporal clustering algorithms to perform a space and time-series analysis of messages without requiring semantic information. This approach can, for example, detect spatially correlated moving units over time within the environment. Detected patterns trigger follow-up assessment of newly developed situations, resulting in invocations of various doctrine-based computational models, including causal static and dynamic Bayesian belief networks. The invoked models then perform SA based

on other observables propagated as evidence into the models. The approach extends further in recognizing significant patterns without relying on doctrinal knowledge. Instead, we make use of latent semantic indexing (LSI), which is a proven technique in text based information retrieval applications. We leverage LSI to extract underlying patterns from observables reported in formatted (e.g. USMTF) or plain text messages. These patterns establish a "normal" profile against which subsequent incoming observations are matched so as to detect any unusual activities (e.g. large scale attack preparation).

Issues for SA
1. Model Based Reasoning—closed form of reasoning and model construction process is time consuming
2. Traditional Knowledge Discovery—requires large amount of training data
3. Link Analysis—manual process and not able to handle large amount of data
Challenges for SA
1. Rapid construction of models
2. BN—for model building (all pair-wise interactions)
3. Unsupervised clustering techniques for large volumes of data to generate normalcy and determine "something is going on"
4. Automation to find "needle in a haystack"

3.3. Collaborative Situation Awareness

"Representation and Contribution-Integration Challenges in Collaborative Situation Assessment" Daniel D. Corkill

Blackboard systems are an ideal architecture for situation assessment involving large data volumes and heterogeneous data and knowledge sources. However, the ad hoc confidence and belief values used in traditional blackboard applications have led to criticism of the blackboard approach and spawned efforts to combine collaborative blackboard-system techniques with more "principled" graphical-network representations. We discuss two important collaborative-assessment challenge areas: 1) principled blackboard representations and 2) principled integration of contributions made by independent knowledge-source entities. The complexity of these challenges is highlighted using a simple assessment scenario, shown in Fig. 8(a).

The effectiveness of blackboard systems is the product of a number of architectural capabilities working in concert. The first important capability is the control flexibility provided by indirect, anonymous, and temporally disjoint interaction among software entities. The blackboard-system control shell can delay execution of a knowledge-source (KS) execution without having to modify an explicit process or worry about managing the data needed by the delayed KS—they remain on the blackboard. Similarly, KS activations can be exe-

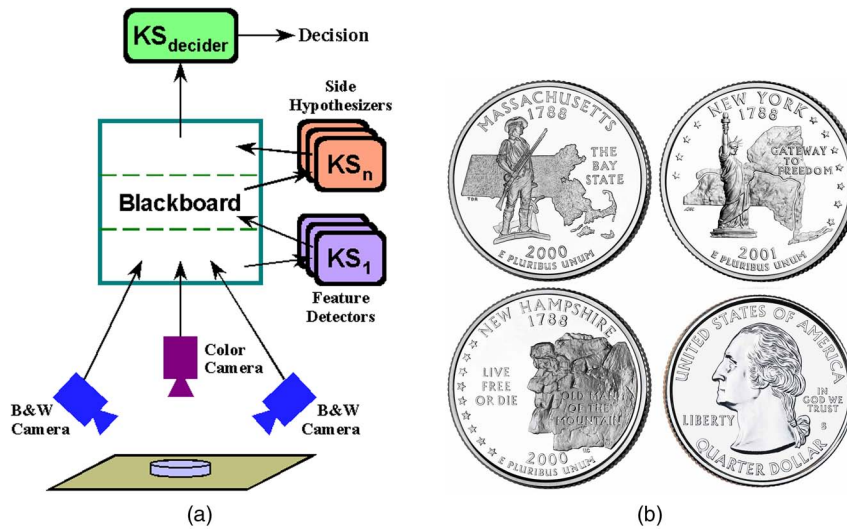


Fig. 8. Fair coin detector.

cuted earlier than normal—whenever there appears to be sufficient information for them to perform useful work. Preliminary efforts in applying graphical belief networks to blackboard systems have focused on a principled representation of the developing solution on the blackboard [34]. Current beliefs are represented on the blackboard as disconnected graphical network [9, 10, 29]. The emphasis should be on making the integration of the contributions made by diverse entities well founded. This can only be achieved by modeling how these contributions are generated and how they relate to one another. For example, if two KSs use the same data and produce similar results using different computational approaches, how independent are the results? Are they redundant (with no added certainty in the results) or complementary (in the sense that each has the potential to make mistakes on certain data values, but these mistakes are fully independent of one another)?

The Fair-Coin Problem: To illustrate these challenges, consider a simple collaborative-assessment problem of deciding if a U.S. quarter is a fair coin (has a head and a tail) by observing a series of coin flips. A priori we are told that there is a 50% chance that the quarter is either two-headed or two-tailed. We have a tabletop that can be viewed by three cameras: two black-and-white cameras and a color camera (Fig. 8(a)). Images feed into our assessment architecture that includes a number of KSs. There are low-level KSs that attempt to identify coin features, higher-level KSs that aggregate features to hypothesize coin sides, and a decider KS that makes the fair or non-fair-coin designation. The goal is to make a principled determination with a specific confidence with as few flip observations as possible. Adding to the complexity is the U.S. 50 State Quarter program, where a new quarter with a state-specific reverse side is issued every 10 weeks in the order that the states were admitted into the Union (Fig. 8(b)).

Issues for SA
1. Blackboard architectures
Different knowledge sources
Benefit from shared information
Bayesian blackboard systems
Graphical belief nets (procedural)
2. Integration of contribution systems
Challenges for SA
1. Representation of uncertainty and certainty
2. Develop entity-specific behavioral specifications of contributions
3. Specifications provided by user for computer to learn
4. Development of feature-identification Knowledge-source
5. Use of characteristics in concert
6. How to deal with mistakes in condition characterizations

3.4. Human Aided Situation Awareness

“Human-Aided Multi-Sensor Fusion” Enrique H. Ruspini, Artificial Intelligence Center, SRI International

In multi-sensor fusion problems, relevant knowledge cannot be completely represented by computer models. In these cases, it is necessary to implement mechanisms that permit human experts to apply the full range of knowledge that only they can master. We identify two fundamental requirements for such a system. It is first necessary to identify properties of a reasoning system that may be visualized by humans so as to judge the credibility and reliability of its results. In addition, it is necessary to implement control and review procedures that may be applied by humans to improve fusion results. We believe that any sophisticated human-aided multi-sensor system that addresses these two needs must provide the following capabilities:

- a) Knowledge acquisition procedures
- b) Explicit representation of multi-sensor knowledge

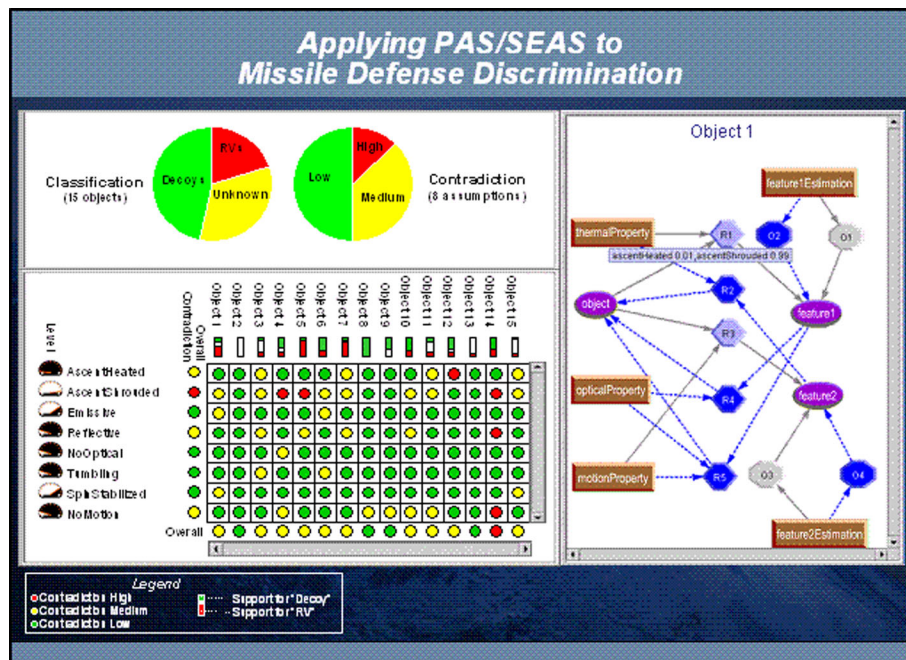


Fig. 9. Structural evidential argumentation system.

- c) Quantitative indicators of properties of fusion results
- d) Intuitive, understandable displays of those properties
- e) Interactive techniques to improve the quality of fusion results

We propose a human-aided multi-sensor fusion system based on the integration of the Probabilistic Argumentation System (PAS) [4], developed by Lockheed Martin, and the Structural Evidential Argumentation System (SEAS) [25], developed by SRI International, shown in Fig. 9. These two software tools implement variants of the Dempster-Shafer (DS) calculus of evidence [19]. PAS is a formalism that explicitly encodes assumptions by means of logical rules in the context of a generalized probabilistic framework. The reasoning procedures of PAS produce measures of support and plausibility for various conclusions while also providing mechanisms to explain the nature of the inferential chains employed to arrive at those results. SEAS permits the recording of analytical processes employed by intelligence analysts to derive their findings. SEAS was originally developed to support collaborative reasoning among multiple analysts. SEAS provides intuitive graphical displays that enable analysts to review analytical processes, their underlying assumptions, and the nature of the processes employed to arrive at conclusions. In practice, the structured-argumentation processes employed by SEAS have been shown to facilitate quick understanding of analytical processes while permitting capture of the collective thinking of groups of analysts.

The integration of PAS and SEAS attempts to satisfy the previously requirements by developing:

- a) Logical rules to facilitate the acquisition and explicit representation of knowledge
- b) DS calculus of evidence to provide a powerful mechanism to model sensor evidence and uncertain knowledge
- c) Explanations about the fusion processes to permit quantification of the relevance of various knowledge items and the detection and identification of contradictions while enabling consideration of alternative hypotheses
- d) Graphical displays to facilitate understanding of inferential chains and their conclusions
- e) Interactive control and review mechanisms to permit humans to correct arguments to increase the utility of conclusion and fusion results

Issues for SA

1. Knowledge acquisition systems
2. Explicit representation of multi-sensor knowledge
3. Quantitative indicators of properties of results
4. Intuitive, understandable displays of those properties
5. Interactive techniques to improve fusion results quality

Challenges for SA

1. Logical rules to facilitate acquisition
2. DS—evidence for uncertain knowledge
3. Explanation of process—evidence and contradiction
4. Graphical displays to facilitate inferential chains
5. Interactive control for corrections and utility of conclusions

3.5. User Refinement—Level 5 of DFIG Model

“DFIG Level 5 (User Refinement) issues supporting Level 2 (Situation Assessment).” Erik Blasch

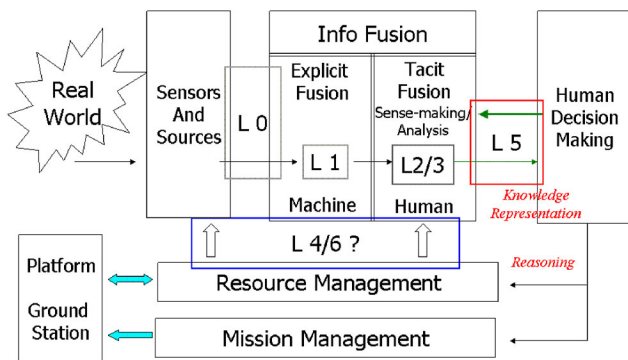


Fig. 10. DFIG 2004 model.

The current fusion model supporting the evaluation and deployment of sensor fusion systems is the User-Fusion model, [7], shown in Fig. 3, with upgrades from the current Data Fusion Information Group¹ (DFIG) (which is the current JDL). The key for SA is the user's mental model [1]. The mental model is the representation of the world as aggregated through the data gathering, IF design, and the user's perception of the social, political, and military situations.

The DFIG model, shown in Fig. 10, separates the data fusion and management functions. Management functions are divided into sensor control, platform placement, and user selection to meet mission objectives. Level 2 (SA) includes tacit functions which are inferred from level 1 explicit representations of object assessment. Since the unobserved aspects of the SA problem can not be processed by a computer, user knowledge and reasoning is necessary. The current definitions, based on the revised JDL fusion model [7], include: (see for other revisions [24])

Level 0—Data Assessment: estimation and prediction of signal/object observable states on the basis of pixel/signal level data association (e.g. information systems collections);

Level 1—Object Assessment: estimation and prediction of entity states on the basis of data association, continuous state estimation and discrete state estimation (e.g. data processing);

Level 2—Situation Assessment: estimation and prediction of relations among entities, to include force structure and force relations, communications, etc. (e.g. information processing);

Level 3—Impact Assessment: estimation and prediction of effects on situations of planned or estimated actions by the participants; to include interactions between action plans of multiple players (e.g. assessing threat actions to planned actions and mission requirements, performance evaluation);

¹Frank White, Otto Kessler, James Llinas, Alan Steinberg, Dave Hall, Ed Waltz, Gerald Powell, Mike Hinman, John Salerno, Erik Blasch, Dale Walsh, Chris Bowman, Mitch Kokar, Joe Karalowski, Richard Antony.

Level 4—Process Refinement (an element of Resource Management): adaptive data acquisition and processing to support sensing objectives (e.g. sensor management and information systems dissemination, command/control).

Level 5—User Refinement (an element of Knowledge Management): adaptive determination of who queries information and who has access to information (e.g. information operations) and adaptive data retrieved and displayed to support cognitive decision making and actions (e.g. human computer interface).

Level 6—Mission Management (an element of Platform Management): adaptive determination of spatial-temporal control of assets (e.g. airspace operations) and route planning and goal determination to support team decision making and actions (e.g. theater operations) over social, economic, and political constraints.

For SA, the user must (1) prioritize information needs to the fusion manager, (2) require reliable and validated information, and (3) seek patterns [6]. The information priority is based on the information desired. The user must have the ability to choose or select the objects of interest and the processes from which the raw data is converted to the fused data. One of the issues in the processing of fused information is related to ability to understand the information origin or pedigree. It is important to note that reliability and validity are two different concepts. A piece of information can be 100% reliable and either totally diagnostic (100% validity) or un-diagnostic (0% validity) in predicting information. However, the less reliable the information, the less valid it is because of the inherent uncertainty (i.e., error) in the information itself.

Users have individual differences for Reasoning Methods (RM) and thus, the coordination between the user and the machine needs to be flexible. An example is that one user might look at sensor data while another might plan missions (see Fig. 10). The responsibility of the user thus determines the information needs requirements for SA. To be able to facilitate many users, a control strategy needs to be defined wherein the user can query and update the database. One way to facilitate user opportunities, a standard set of metrics for Knowledge Representation (KR) should be designed that afford Quality. Blasch [6] explored the concepts of level 2, situation awareness or assessment, by detailing the user needs of attention, workload, and trust which can be mapped into metrics of timeliness, throughput, confidence, and accuracy. Table II lists metrics for SAW as referenced to the communications, human factors, automatic target recognition (ATR), and target tracking literature. SA is hard to define and creates interface problems if not standardized. Information needs of fusion systems for KR and RM need rigorous testing in experimental designs to define SA Products. Additionally, dynamic updating of Knowledge Delivery for planning requires timely and reliable data for reasoning.

TABLE II
Metrics for Fusion and Situational Awareness

COMM	Human Factors	Sit Aware*	ATR	TRACK
Delay	Reaction Time	Timeliness	Acquisition/Run Time	Update Rate
Probability of Error	Confidence	Confidence	Prob. (Hit), Prob. (FA)	Probability of Detection
Delay Variation	Attention	Purity, Precision	Positional Accuracy	Covariance
Throughput	Workload	Usage	# Images	No. Targets
Cost	Cost	Utility	Collection platforms	No. Assets
Security	Trust	Reliability	Ontology, Taxonomy	Cooperative Nav.

*Tadda et al. propose some of these for Cyber SA: purity for quality detection, evidence recall, and attack score [35].

Issues for SA
1. Standard Set of Metrics for Knowledge Representation
2. User (individual differences) for Reasoning Methods
3. Dynamic updating of Knowledge Delivery for Planning
4. Users desire a variety of SA display information
5. Information Needs of fusion systems for KR and RM
Challenges for SA
1. Scoping a common terminology and metrics
2. Affording control strategies for different users
3. KR must afford timeliness for reasoning
4. Interface design must be flexible (KR) to different users
5. Rigorous testing in experimental designs to define SA

4. CONCLUSIONS

The panel discussion highlighted many different, but common themes that are SA issues and proposed a variety of challenges of SA for the future. The common issues are: (1) User focused (perceptual, interactive, control), (2) developing Process models for behavioral modeling and updating the models (e.g.—Bayes Nets, procedural/logical, perceptual, learning), (3) determining the Context—operational situation (i.e. domain dependent), (4) detailing the Meaning (i.e. semantics and syntactic relations), and (4) the need for a standard set of SA Metrics (e.g. trust, bounds, uncertainty). The common challenges include (a) explanation of process that addresses evidence accumulation and contradiction constraints for knowledge representation and reasoning, (b) graphical displays to facilitate inferential chains, collaborative interaction, and knowledge representation, and (c) interactive control for corrections and utility assessment for knowledge management. While these lists are notional, the information presented is from a panel of participants who have all tried to build SA tools for the operator and thus, the issues and challenges are posed from experience. The next phase of the collaboration research on SA design, issues, and challenges will focus on a set of process models. Possible directions and extensions include utilization of intelligent agents to emulate team cognition [38], use of gaming concepts for hypothesis generation and data understanding, and rapid evolution of human-computer interaction such as 3-D full immersion environments.

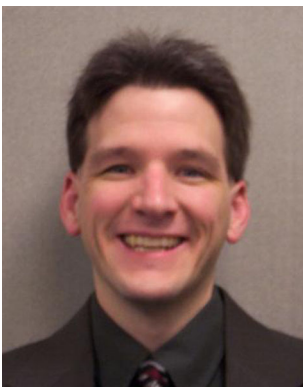
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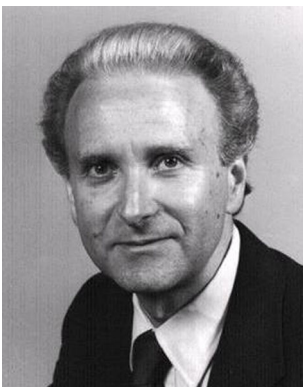
Erik Blasch received his B.S. in mechanical engineering from the Massachusetts Institute of Technology and Masters in mechanical, health science, and industrial engineering from Georgia Tech and attended the University of Wisconsin for an M.D./Ph.D. in Mech. Eng./Neurosciences until being called to active duty in the United States Air Force. He completed an M.B.A., M.S.E.E., M.S. Econ. M.S./Ph.D. psychology (ABD), and a Ph.D. in electrical engineering from Wright State University (WSU). He is currently still a student in Air Staff College.

Dr. Blasch is an information fusion evaluation tech lead for the Air Force Research Laboratory—COMprehensive Performance Assessment of Sensor Exploitation (COMPASE) Center, adjunct EE and BME professor in at WSU and AFIT, and a reserve Major with the Air Force Office of Scientific Research. He was a founding member of the International Society of Information Fusion (ISIF) in 1998 and is the 2007 ISIF President. Dr. Blasch has many military and civilian career awards; but engineering highlights include team member of the winning '91 American Tour del Sol solar car competition, '94 AIAA mobile robotics contest, and the '93 Aerial Unmanned Vehicle competition where they were first in the world to automatically control a helicopter. Since that time, Dr. Blasch has focused on automatic target recognition, targeting tracking, and information fusion research compiling 180 scientific papers and book chapters. He is active in IEEE (AES and SMC) and SPIE including regional activities, conference boards, journal reviews, and scholarship committees; and participates in the Data Fusion Information Group (DFIG), the Program Committee for the DOD Automatic Target Recognition Working Group (ATRWG), and the SENSIAC National Symposium on Sensor and Data Fusion (NSSDF).



Ivan Kadar received the B.E.E. degree from City College of CUNY, the M.S.E.E. degree from Columbia University and the Ph.D. degree in electrical engineering from Polytechnic Institute of New York.

In 2000 he founded Interlink Systems Sciences, Inc. providing scientific and technical consulting services in systems, sensors and algorithms with applications to all levels of multi-source information/sensor/data fusion and related technologies, and currently consults part-time to private industry and universities. In addition, he is also currently employed at Northrop Grumman Corporation Integrated Systems, as Associate Fellow, and serves as technical advisor in the broad area of Information Fusion Technologies. Previously, he worked for Grumman/Northrop Grumman Corporation in the roles of consultant, principal scientist, technical advisor, principal engineer and technical specialist responsible for conceptual design, technical direction, original applied research/advanced development, organization and supervision of professionals, management of R&D programs and integration of advanced technologies. He initiated, managed and/or was principal investigator on hands-on research/development in all levels of information/sensor/data fusion, tracking, automated target recognition, knowledge-based intelligent systems, communications, and systems integration for 19 years. He also worked for IBM T. J. Watson Research Center as a research staff member in the Systems Analysis, Algorithms, Networking and Satellite Communications Group of Computer Sciences. His experience/research areas of interests include systems design and synthesis; geometrical, connection and resource management aspects of centralized, distributed and adaptive information fusion and tracking, and its interactions with higher-level fusion processing; feature-aided multi-sensor multi-target tracking and robust association; perceptual reasoning and anticipation in situation assessment and intent modeling; uncertainty models; evidential reasoning; knowledge representation and management; long-term prediction of target states using contextual knowledge; sensor modeling; fusion systems measures-of-merits, optimization and performance predictions; robust estimation with applications to tracking and sensor data processing; pre-and-post-detection fusion; statistical image processing; target/pattern recognition; ad-hoc sensor networks; communications and radio navigation systems; distributed decision making; artificial intelligence; decision aiding; and medical informatics with applications to real-world problems.



Dr. Kadar has authored/coauthored over 100 papers, book chapters, edited two books and fifteen volumes of the *Signal Processing, Sensor Fusion and Target Recognition* conference which he organizes and chairs; chair for Sensor Data Exploitation and Target Recognition Conferences of the SPIE Defense and Security Symposia; serves on the program and/or technical committees for the above, and for some of the International Conferences on Information Fusion; elected to the editorial board of the on-line journal *Advances in Information Fusion* of ISIF, and served on the editorial board of the *International Journal of Information Fusion*. He is recipient of the IEEE Region I award, and two IEEE AES M. Barry Carlton Best Paper Awards. He is reviewer for several journals. He was elected in 2005 to serve on the Board of Directors of the International Society of Information Fusion (ISIF) (2006–2008); and elected as SPIE Fellow in 2007.

John Salerno received an A.A.S. degree in mathematics from Mohawk Valley Community College, a B.A. in math and physics from SUNY at Potsdam, a M.S.E.E. from Syracuse University and a Ph.D. in computer science from SUNY Binghamton. His research interests include neural networks and natural language. He began his career with the Air Force Laboratory in 1980 as a computer scientist in the Communications Networks Branch. The nature of his assignments at AFRL has included positions as research scientist, team leader, branch chief and assistant division chief. Over his outstanding career, he has effectively honed and applied his unique skills to solve complex operational Air Force and Intelligence Community problems. In doing so, Dr. Salerno has established a prodigious record of designing and successfully transitioning innovative solutions from early in-house feasibility demonstrations to fielded operational systems, many of which are supporting customers worldwide today.

Dr. Salerno has authored over 40 publications and 10 DoD technical publications, has pioneered 3 Air Force Inventions (patents pending), and has consistently proven his ability to organize and advance the state-of-the-art in Information Fusion technology. John's reputation for excellence has earned him advisory positions with 4 international conferences as well as invited membership with the DoD International Collaboration on Communications; OSD Science and Technology Panel on Data Fusion, and the DoD Assessment of Redeployment of Personnel to the Persian Gulf. As a technical leader, he has personally developed and guided multiple teams to deliver seminal operational capabilities such as Project Broadsword, HyperText Markup Language (HTML) Interface for Imagery Product Library (IPL), and the Client Server Environment. He envisioned, organized, and built a unique Intelligence/Air Force capability, the Joint Integration Test Facility (JITF), to perform initial operational evaluation on critical intelligence software systems. He currently leads the world-recognized Fusion 2+ group to develop and integrate technologies from across AFRL and other DoD research laboratories to deliver a groundbreaking warfighter capability to collect, interpret, and anticipate adversarial actions/intent. He has been married for the past 21 years to Barbara and has three children; Steven, Eric and Nicole.



Mieczyslaw M. Kokar has an M.S. and a Ph.D. in computer systems engineering from Wroclaw University of Technology, Poland.

Dr. Kokar is with the Department of Electrical and Computer Engineering at Northeastern University in Boston. His technical research interests include information fusion, ontology-based information processing, self-controlling software and modeling languages. In particular, he is interested in higher-level information fusion and situation awareness, ontology-based software radios, the specification and design of self-controlling software using the control theory metaphor, ontology development, ontological annotation of information, logical reasoning about OWL annotated information, consistency checking, formalization of the UML language, consistency checking of UML models versus UML Metamodel and of UML Metamodel versus MOF. He teaches various graduate courses in software engineering, formal methods and artificial intelligence. He is a senior member of the IEEE and member of the ACM.

More information about Professor Kokar can be found at his web site: <http://www.ece.neu.edu/groups/scs/kokar>.



Subrata Das received his Ph.D. in computer science from Heriot-Watt University in Scotland and a M.Tech. from the Indian Statistical Institute.

He is the chief scientist at Charles River Analytics, Inc. (www.cra.com) in Cambridge, MA. Subrata leads research projects in the areas of high-level and distributed information fusion, decision-making under uncertainty, intelligent agents, planning and scheduling, and machine learning. His technical expertise includes mathematical logics, probabilistic reasoning including Bayesian belief networks, symbolic argumentation, particle filtering, and a broad range of computational artificial intelligence techniques. Subrata held research positions at Imperial College and Queen Mary and Westfield College, both part of the University of London.

He has published many journal and conference articles. He is the author of the book entitled *Deductive Databases and Logic Programming*, published by Addison-Wesley, and has coauthored the book entitled *Safe and Sound: Artificial Intelligence in Hazardous Applications*, published by the MIT Press. His forthcoming book entitled, *Foundations of Decision Making Agents: Logic, Modality, and Probability*, is due shortly for publication by the World Scientific/Imperial College Press.

Dr. Subrata is a member of the editorial board of the journal, *Information Fusion*, published by Elsevier Science. He is in the process of editing a special issue for the journal relating to agent-based information fusion. Subrata has been a regular contributor, a technical committee/invited panel member, and a tutorial lecturer at each of the last three International Conferences on Information Fusion. He has been invited to join the technical committee at the forthcoming fusion conference to be held in Quebec City in July 2007, and to be part of the guest panel that will discuss lessons learned from level 2 fusion system implementations. He has also been giving a series of tutorials on multi-sensor data fusion on behalf of the Technology Training Corporation.



Gerald Powell is a senior scientist in the Intelligence and Information Warfare Directorate at U.S. Army RDECOM, CERDEC, Fort Monmouth, NJ. His research focuses on computational approaches to intelligence analysis and information gathering.

Dr. Powell is a senior member of the IEEE and a member of the American Association for Artificial Intelligence.

Daniel Corkill received the Ph.D. in computer science from the University of Massachusetts Amherst in 1983.

Dr. Corkill is a senior research scientist and associate director of the Multi-Agent Systems Laboratory in the Department of Computer Science at the University of Massachusetts Amherst. He is a leading authority in the areas of blackboard systems, multi-agent organizations, and collaborating software technologies. Corkill founded and served as President of Blackboard Technology Group (BBTech), which specialized in commercial blackboard-system software (GBB) and collaborating software research. At BBTech, he helped develop GBB applications in many domains, including the Radarsat-I mission control system. GBB received Object Magazine's Editors Choice award for software in 1996. Prior to founding BBTech, Corkill was an associate research professor in computer science at the University of Massachusetts Amherst. He is currently leading development of blackboard-based systems for the U.S. Air Force, DARPA, and DND Canada. He also heads the GBBopen Project (<http://GBBopen.org/>), which is providing high-performance, blackboard-system and collaborating-agent technology as open source.



Enrique H. Ruspini received his degree of Licenciado en Ciencias Matemáticas from the University of Buenos Aires, Argentina, and his doctoral degree in system science from the University of California at Los Angeles.

He is a principal scientist with the Artificial Intelligence Center, SRI International (formerly Stanford Research Institute), which he joined in 1984. Prior to joining SRI, he held positions at the University of Buenos Aires, the University of Southern California, UCLA's Brain Research Institute, and Hewlett-Packard Laboratories.

He is one of the earliest contributors to the development of fuzzy-set theory and its applications, having introduced its use to the treatment of numerical classification and clustering problems. He has also made significant contributions to the understanding of the foundations of fuzzy logic and approximate-reasoning methods. His recent research has focused on the application of approximate-reasoning techniques to the development of systems for intelligent control of teams of autonomous robots, information retrieval, information fusion, qualitative description of complex objects, intelligent data analysis, and knowledge discovery/pattern matching in large databases.

He has lectured extensively in the United States and abroad, is a Fellow of the Institute of Electrical and Electronic Engineers, a First Fellow of the International Fuzzy Systems Association, a Fulbright Scholar, and a SRI Institute Fellow. He was the general chairman of the Second IEEE International Conference on Fuzzy Systems (FUZZ-IEEE'93) and of the 1993 IEEE International Conference on Neural Networks (ICNN'93). He is one of the founding members of the North American Fuzzy Information Processing Society and a recipient of that society's King-Sun Fu Award. He is a former member of the IEEE Board of Directors (Division X Director, 2003–2004), the past-president (President-2001) of the IEEE Neural Networks Council, and its past Vice-President of Conferences. He has led numerous IEEE technical, educational, and organizational activities, is also a member of the Administrative Committee of the IEEE Computational Intelligence Society.

Dr. Ruspini is the Editor in Chief (together with P. P. Bonissone and W. Pedrycz) of the *Handbook of Fuzzy Computation*, a member of the Advisory Board of the *IEEE Transactions on Fuzzy Systems*, the *International Journal of Fuzzy Systems*, and the *Journal of Advanced Computational Intelligence and Intelligent Informatics*, and a member of the editorial board of the *International Journal of Uncertainty, Fuzziness, and Knowledge-Based Systems*, *Fuzzy Sets and Systems*, and *Mathware and Soft Computing*.

